What is claimed is:

1. The method of treating heart disease by permanently replacing or augmenting cardiac function comprised of implanting a prosthetic blood pump within one or more chambers of the heart.

2. The method of surgical implantation of prosthetic blood pumps within the heart, comprised of:

(a) creating surgical access to one or more of the four major chambers or arteries of the heart such that the major coronary arteries are preserved;

(b) suturing one or more connectors within the heart to permit attachment of the blood pump;

(c) testing the suture lines and repairing any leaks;

(d) securely attaching the blood pump to the connectors;

(e) removing any air trapped within the blood chamber;

(f) initiating pumping;

(g) repairing the surgical incisions.

3. The method of surgical implantation of prosthetic blood pumps within the heart described in Claim 2 in which one or more of the natural valves of the heart are replaced with prosthetic valves.

4. The method of surgical implantation of prosthetic blood pumps within the heart described in Claim 2 in which the size of one or more chambers of the heart into which the components of the artificial heart system are implanted is enlarged using a muscle graft or split-thickness flap of cardiac muscle tissue.

5. The method of surgical implantation of prosthetic

blood pumps within the heart described in Claim 2 in which the inflow anastomosis is made within the heart, and the outflow anastomosis is made outside the heart to either the aorta or the pulmonary artery.

6. The method of surgical implantation of prosthetic blood pumps within the heart described in Claim 2, including attachment of system components implanted within the heart to additional components located outside of the heart.

~~7. A left ventricular or biventricular cardiac output~~ restoration system for the treatment of heart ~~failure~~ that incorporates blood-pumping elements of sufficiently-compact size and anatomic configuration to be implanted within the heart, such that said pumping elements function independently or in conjunction with natural or prosthetic heart valves to provide the entire cardiac output required for the systemic (left) circulation and to provide all, none, or part of the cardiac ~~output required for the pulmonic (right) circulation.~~

8. The artificial heart of Claim 7 in which the blood pumping means comprise a rotary (hydrodynamic) axial-flow pump, mixed-flow pump, or centrifugal pump.

9. The artificial heart of Claim 7 in which the pumping means comprises a polymer blood sac and a periodically electrically-stimulated skeletal muscle graft of living tissue from the patient or transplanted muscle tissue from another individual.

10. The artificial heart of Claim 7 having a textured outer surface layer of appropriate material and porosity to permit tissue ingrowth and minimize infection.

~~11. The electrically-powered intraventricular~~

artificial heart of Claim 7 including control means to vary the cardiac output produced according to the physiological needs by varying the electrical power input into the energy-convertor.

12. The artificial heart defined in Claim 7 in which said blood pumping elements are comprised of a pulsatile positive displacement pump.

13. The pulsatile positive displacement artificial heart of Claim 12 further defined in that it has a mechanism that includes compression and expansion of a gas volume, thereby requiring no compliance chamber.

14. The pulsatile positive displacement artificial heart of Claim 12 utilizing alternate pumping of blood within two chambers of the heart in such an arrangement that no compliance chamber outside the heart is required.

15. The pulsatile positive displacement heart of Claim 12 having venting means to a compliance chamber located outside the heart or having venting means to the atmosphere.

~~16. An electrically powered intraventricular~~ artificial heart, comprising:

(a) inflow means implantable within the heart to receive blood from the left or right atrium;

(b) blood pumping means implantable within the heart adapted to act upon blood received from the inflow means and eject said blood at increased pressure into the aorta or pulmonary artery;

(c) electrical energy-convertor means implantable within the heart adapted to receive electrical energy from a power source outside the heart via a cable and to convert said ~~electrical energy to mechanical energy~~ applied to pump the blood.

17. The intraventricular electrically-powered artificial heart of Claim 16 that includes redundant components capable of sustaining the life of the patient in the event of a single component failure.

18. The intraventricular electrically-powered artificial heart of Claim 17 in which one of said redundant elements comprises a pair of electric motors.

19. The electrically-powered intraventricular artificial heart of Claim 16 including control means to vary the cardiac output produced according to physiological needs by varying the electrical power input into the energy convertor.

20. A pulsatile positive displacement artificial heart capable of functioning without an air vent or compliance chamber, comprising:

(a) blood pumping means having a flexible diaphragm or sac capable of pumping blood when it is acted upon by mechanical or hydraulic forces;

(b) housing and hydraulic fluid coupling means containing hydraulic fluid and operatively in contact with said blood pumping diaphragm or sac to actuate it hydraulically;

(c) a hermetically-sealed gas-filled metal bellows within said housing immersed in the hydraulic fluid such that changes in volume of the bellows results in a net force exerted on the hydraulic fluid;

(d) electrically-actuated energy-convertor means to mechanically expand and contract the bellows and provide the motive force to actuate the diaphragm;

(e) means to supply power to the electrically-actuated energy convertor;

(f) means to control the output of the heart.

21. The artificial heart of Claim 20, in which:

(a) the electrically-activated energy-convertor means comprises one or more electric motors operatively connected to the bellows via a scotch yoke and shaft supported by a linear bearing;

(b) the pressure of the gas is maintained below atmospheric pressure;

(c) a spring comprised of a stack of belleville washers is utilized to oppose atmospheric forces tending to reduce the volume of gas within the bellows.

22. A positive displacement pusher-plate-actuated artificial heart, comprising:

(a) a roll sock diaphragm supported within the housing of a combined blood pump/actuator device;

(b) a pusher-plate fixed to a central portion of the roll sock diaphragm appropriately sized and configured to guide said diaphragm;

(c) means to actuate the pusher-plate with a linear back-and-forth motion comprising the systolic and diastolic cycle;

(d) a metal bellows having one end mechanically fixed to said pusher-plate and the other end fixed to the housing such that a chamber containing hydraulic fluid is formed, bounded by the outside of the metal bellows, the inside of the housing, and the rolling diaphragm;

and further defined in that the size and geometry of said roll sock diaphragm, pusher-plate, and the bellows are arranged such that the volume of blood moved by the diaphragm during the cycle closely matches the change of volume within the bellows during the cycle, thereby retaining the diaphragm in the optimal rolling configuration through the action of the hydraulic fluid within said chamber.

23. The artificial heart of Claim 22 in which the metal bellows is hermetically sealed to the pusher-plate at one

end and to a housing on the other end, is actuated by an electro-mechanical mechanism contained therein, alternately compresses and expands the gas therein during the operating cycle, and thereby requires no air vent or compliance chamber.

24. The artificial heart of Claim 22 in which said means to actuate the pusher-plate comprises an electro-mechanical actuator contained within said combined blood pump/actuator device, further including conduit means through which fluid within the bellows and the portion of the housing containing the electro-mechanical actuator is alternatively driven in and out of a hydraulically-actuated second blood pump located in an additional chamber of the heart.

25. The artificial hear of Claim 22 in which the metal bellows is fixed to the pusher-plate on one end and to a housing on the other end and includes conduit means through which gas or fluid within the bellows may be vented to the atmosphere or to a compliance chamber.

26. The artificial heart of Claim 25 in which the pusher-plate is actuated by an electro-mechanical mechanism contained within the bellows and housing.

27. The artificial heart of Claim 22 in which the pusher-plate is actuated by an electro-mechanical mechanism comprised of one or more electric motors and a scotch yoke coupled thereto.

28. The artificial heart of CLaim 22 in which the means to actuate the pusher-plate comprises an electro-mechanical device utilizing a ball screw or roller screw driven by an electric motor in which reversing direction of motion of the pusher-plate is accomplished by reversing the direction of rotation of the motor.

29. An attachment and alignment system used to connect a surgically-implanted artificial heart diaphragm in proper alignment with the pusher-plate of a blood pump comprising a conical rigid-support member fixed to the diaphragm adapted to mate with a corresponding conical portion on the pusher-plate and including attracting magnetic elements within the diaphragm and pusher-plate adapted to align and adhere the diaphragm to the pusher-plate during assembly at surgery.

30. An artificial heart connector system comprising:

(a) a sewing cuff formed as a seamless, generally tubular or conical, extension of an artificial heart diaphragm, sac, or other compressible blood-pumping member;

(b) attachment means disposed radially around said diaphragm, sac, or other compressible blood-pumping member and bonded thereto in the vicinity of the sewing cuff;

(c) clamping means to affix said attachment means to the artificial heart after said sewing cuff has been sutured to the appropriate structure of the vascular system.

31. The artificial heart connector of Claim 30 in which said attachment means constitutes a flexible polymeric flange.

32. The artificial heart connector system of Claim 30 wherein said clamping means constitutes two threaded members adapted to compress and retain said attachment means between them when the threads are engaged and tightened.

33. A bearing system to mechanically suspend a device for motion within the blood stream comprising a wire and means to maintain said wire in tension within the blood stream such that said wire passes through a hole in the device and thereby retains the device while permitting motion in at least one plane.

34. The bearing of Claim 33 in which the wire is composed of a hard corrosion- and wear-resistant metal, round in cross-section, that passes through an elongated cylindrical hole in a suspended rotor of a blood pump in which the bore of the hole very closely matches the diameter of the wire without binding and the material of the rotor through which the wire passes is resistant to frictional wear.

35. A bearing system as defined in Claim 34 further defined in that the suspended device includes magnetic means that interact with magnetic means outside the bloodstream in the vicinity of the device so as to further limit the motion of the device while still permitting motion in at least one plane.

36. The bearing system described in Claim 34 in which the rotor, suspended for rotational movement by the wire in tension, contains magnetic means which magnetically interact with magnetic means outside the blood stream to suspend the rotor axially on the wire and magnetically counteract thrust loads such that the rotor is prevented from contacting the housing of the blood pump during rotation.

37. An artificial heart connector system comprising:

(a) a generally tubular or conical flexible vascular conduit adapted at one end to be sutured to the appropriate structure of the vascular system and at the other end formed as or affixed to an attachment flange having a tapered alignment surface;

(b) a mating tapered alignment seat on the artificial heart having the angle of taper and inside diameter matched to the diameter and taper of the alignment surface of said attachment flange;

(c) radially disposed clamping means positionable around said attachment flange and said mating seat adapted to

axially clamp and retain said flange between said seat and said clamping means in concentric radial alignment.

38. The artificial heart connector system of Claim 37 wherein said clamping means constitutes two threaded members adapted to compress and retain said attachment flange between them when the threads are engaged and tightened.

39. A seamless intraventricular diaphragm-type blood pump adapted to function in conjunction with inflow and outflow valves supported by the natural heart comprising:

(a) a polymeric sewing cuff and blood diaphragm with flexible connector means sufficiently flexible to permit them to be sutured within the natural ventricular chamber in close proximity to the valves;

(b) base means to support a fluid-actuated diaphragm over a chamber;

(c) conduit means through which fluid may be introduced into said chamber to actuate said diaphragm means;

(d) rigid housing support and attachment means to clamp and seal the base member to the sewing cuff and blood diaphragm via said connector means in the appropriate position for the separate diaphragm layers to act as a multi-layer diaphragm and achieve a long life flex.

40. The blood pump as defined in Claim 39 in which the shape of the diaphragm includes a conical section capped by a segment of a sphere such that as the diaphragm moves between its end-systolic and end-diastolic position it may roll in the area of the conical section.

41. The method of fabricating an artificial heart blood diaphragm and housing as an integral unit in which a portion of said diaphragm lies directly against a portion of the housing without being bonded thereto comprising:

(a) fabricating the housing member with a sufficiently-elastic wall in the region of desired unbonded contact with the blood diaphragm to permit the housing to be stretched over a mold;

(b) mounting said housing over a hollow blood diaphragm mold with the portion of the housing against which the diaphragm will lie in unbonded contact stretched over the outer diameter of the mold, said mold having an inner contour matching the inner contour of the unstretched housing in the region where the diaphragm is to lay in unbonded contact thereagainst;

(c) clamping the housing over said mold in said position;

(d) solution-casting the blood diaphragm against the inner surface of the hollow mold and simultaneously forming a bonded blood-contacting lining within the housing covering the exposed surface of the housing;

(e) curing the solution-cast polymer;

(f) removing the diaphragm housing assembly from the mold to permit the stretched section of the housing to return to its non-stretched position.

42. An artificial heart structural component adapted to reduce the stress on the blood-contacting diaphragm of a multi-layer diaphragm-type artificial heart after long periods of pumping during which creep of the diaphragm layers occurs, in which type of artificial heart the blood diaphragm is cast as an integral unit with a blood-contacting layer lining the inside of the blood chamber (housing) of said artificial heart, comprising:

(a) a structure in the region of attachment of the blood-contacting diaphragm to the housing in which a portion of said diaphragm lies directly against a portion of the housing without being bonded thereto such that as layers of the diaphragm experience creep and elongate after prolonged pumping said unbonded portion of the blood diaphragm is free to roll away from the housing without being torn.

43. The blood pump of Claim 39 in which a vent is provided to evacuate excess air between the blood diaphragm and other layers of the diaphragm during assembly at surgery and in which means to tightly seal the vent are provided.

44. An intraventricular artificial heart for use in conjunction with valves supported within the natural heart comprising:

(a) a flexible polymeric seamless blood-pumping sac having a sewing cuff adapted to be sutured within the natural ventricle closely adjacent to the valves;

(b) means to rigidly support said blood sac in the region of the suture line such that compressive forces upon the sac do not distort or tear the suture line;

(c) a skeletal muscle graft surrounding the blood sac, implantable within the ventricle and arranged such that contraction of the muscle caused by an electric stimulator compresses the sac, thereby ejecting a portion of the blood contained therein through the outflow valve into the arterial system;

(d) means to secure the blood sac to the muscle graft and to the natural cardiac tissue such that the blood sac remains in the proper functional position.

45. The intraventricular muscle-powered artificial heart described in Claim 44 including resilient means to expand the blood sac during diastole and thereby aid filling of the device with blood.

46. An intraventricular muscle-powered artificial heart, comprising:

(a) an inner seamless blood sac having a sewing cuff and means for attachment to additional elements of the artificial heart after suturing is completed;

(b) an outer chamber adapted to surround the seamless blood sac and be affixed thereto at surgery;

(c) said outer member comprising a hydraulic fluid-filled device having two concentric hydraulic fluid-containing sacs, the outer sac having flexible portions exposed to be squeezed by a surrounding muscle graft and thereby hydraulically transmit the force to the inside;

(d) means to attach the hydraulic fluid-filled device around the inner blood sac;

(e) means to vent the air in the space between the blood sac and surrounding device during surgery and to seal said vent;

(f) a muscle graft disposed around the aforesaid components adapted to compress the device when stimulated by an electric stimulator and thereby to eject a portion of the blood contained therein through the outflow valve into the arterial system.

47. A muscle-powered intraventricular blood pump of Claim 46 including resilient means to expand the blood sac during diastole and thereby aid filling of the device with blood.

48. A muscle-powered artificial heart system comprising:

(a) hydraulic fluid-actuated intraventricular blood pumping means implanted within one or more of the chambers of the heart;

(b) muscle-actuated hydraulic fluid pumping means connected by a conduit to said intraventricular blood-pumping means;

(c) a muscle graft disposed around said hydraulic fluid pumping means such that upon stimulation of the muscle by an electric stimulator, the muscle contracts and forces the hydraulic fluid to actuate the blood pump and thus expel blood through the outflow valve into the arterial system, and when the

muscle relaxes, hydraulic fluid flows from the blood-pumping means into the hydraulic fluid-pumping means as blood enters the blood pump.

49. The artificial heart as described in Claim 48 including resilient means acting to withdraw hydraulic fluid from the blood-pumping means when the muscle relaxes, and thus aid filling of the heart with blood during diastole.

50. The artificial heart of Claim 48 additionally including a fluid conduit tube which may transverse the body wall by penetrating the skin to permit the blood pump to be actuated by an external source of fluid power during the period of time that the skeletal muscle graft is being conditioned to be able to take over a greater workload during repetitive contraction, said system including means to seal said tube and implant it under the skin when external support is no longer required.

51. The method of surgically implanting an intraventricular artificial heart comprising:

(a) excising the natural heart from the patient;

(b) suturing the intraventricular artificial heart and any requisite prosthetic valves within said excised natural heart;

(c) reimplanting the natural heart together with the intraventricular artificial heart into the patient.

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~~52. An artificial heart, heart assist, or blood~~ pumping device adapted to propel blood therethrough by means of rotary hydrodynamic fluid pumping elements, comprising:

(a) inflow and outflow means by which to connect said device to the vascular system,

(b) blood containing housing means within which the pumping mechanism is contained,

(c) minimally-hemolytic axial flow, mixed flow, or

centrifugal flow rotary pump impeller means, mechanically supported and rotated by magnetically actuated rotor means,

(d) minimally-hemolytic wear-resistant blood-immersed journal bearing means supporting said rotor for rotation such that the exposed junction of the rotating and stationary components of the bearings are washed by high blood flow to prevent thrombus accumulation, and,

(e) power means and magnetic actuator means to provide force to rotate said rotor and impeller means thereby pumping the blood.

53. An artificial heart, heart assist, or blood pumping device adapted to propel blood therethrough without excessive blood damage or thrombosis by means of rotary hydrodynamic fluid pumping elements, comprising:

(a) inflow and outflow means by which to connect said device to the vascular system,

(b) blood containing housing means including a generally cylindrical tubular segment,

(c) axial flow or mixed flow rotary pump impeller means adapted to pump blood with minimal hemolysis, mechanically supported and rotated by magnetically actuated rotor means,

(d) said magnetically actuated rotor means immersed in blood within said generally cylindrical housing segment, and rotatably supported by mechanical radial bearing means,

(e) said rotor means and said generally cylindrical segment of said housing means having therebetween an annular generally cylindrical blood channel through which flows all or part of the blood pumped by the device and across which forces to rotate the impeller are exerted magnetically, and,

(f) power means and magnetic actuator means to provide force to rotate said rotor and impeller means thereby pumping the blood.

54. An artificial heart, heart assist, or blood pumping device adapted to propel blood therethrough without excessive blood damage or thrombosis by means of rotary

hydrodynamic fluid pumping elements, comprising:

(a) inflow and outflow means by which to connect said device to the vascular system,

(b) blood containing housing means including a generally cylindrical tubular segment,

(c) minimally-hemolytic axial flow, mixed flow, or centrifugal flow rotary pump impeller means, axially separated from, and mechanically supported and rotated by magnetically actuated rotor means,

(d) said magnetically actuated rotor means emersed in blood within said generally cylindrical housing segment, and rotatably supported by bearing means,

(e) said rotor means and said generally cylindrical segment of said housing means having therebetween an annular generally cylindrical bladeless blood channel through which all or part of the blood pumped by the device flows without backflow, and across which forces to rotate the rotor are exerted magnetically, and,

(f) power means and magnetic actuator means to provide force to rotate said rotor and impeller means thereby pumping the blood.

2 ~~55~~. The device of claim 1 ~~52~~, in which said bearing means comprise:

(a) a smooth wear-resistant wire maintained in tension to serve the function of a non-rotating shaft, and,

(b) a cylindrical rotating sleeve composed of a wear-resistant material, ~~such as pyrolytic carbon, ceramic, or sapphire,~~ having an elongated hole through which said wire passes of a diameter only slightly larger than the diameter of the wire, such that only a minimal volume of blood occupies the gap between the wire and the sleeve.

12 ~~56~~. The device of claim 11 ~~53~~, in which said bearing means comprise:

(a) a smooth wear-resistant wire maintained in tension to serve the function of a non-rotating shaft, and,

(b) a cylindrical rotating sleeve composed of a wear-resistant material, ~~such as pyrolytic carbon, ceramic, or sapphire,~~ having an elongated hole through which said wire passes of a diameter only slightly larger than the diameter of the wire, such that only a minimal volume of blood occupies the gap between the wire and the sleeve.

57. The device of claim 54, in which said bearing means comprise:

(a) a smooth wear-resistant wire maintained in tension to serve the function of a non-rotating shaft, and,

(b) a cylindrical rotating sleeve composed of a wear-resistant material, such as pyrolytic carbon, ceramic, or sapphire, having an elongated hole through which said wire passes of a diameter only slightly larger than the diameter of the wire, such that only a minimal volume of blood occupies the gap between the wire and the sleeve.

58. The device of claim 52, including control means to vary the blood flow pumped according to the physiological demand, and optionally to provide a pulsatile flow by repeatedly speeding up and slowing down the speed of rotation of the impeller.

59. The device of claim 53, including control means to vary the blood flow pumped according to the physiological demand, and optionally to provide a pulsatile flow by repeatedly speeding up and slowing down the speed of rotation of the impeller.

60. The device of claim 54, including control means to vary the blood flow pumped according to the physiological demand, and optionally to provide a pulsatile flow by repeatedly speeding up and slowing down the speed of rotation of the impeller.

~~61.~~ The device of claim ~~52~~, of sufficiently small size and anatomic configuration to be implanted either within the chamber of the left ventricle, within the chamber of the right ventricle, or both, so as to produce adequate flow and pressure to replace the entire pumping function of the ventricle or ventricles in which it is implanted.

~~62.~~ The device of claim ~~53~~, of sufficiently small size

and anatomic configuration to be implanted either within the chamber of the left ventricle, within the chamber of the right ventricle, or both, so as to produce adequate flow and pressure to replace the entire pumping function of the ventricle or ventricles in which it is implanted.

63. The device of claim 54, of sufficiently small size and anatomic configuration to be implanted either within the chamber of the left ventricle, within the chamber of the right ventricle, or both, so as to ~~priduce~~ produce adequate flow and pressure to replace the entire pumping function of the ventricle or ventricles in which it is implanted.

~~64~~. The device of claim ~~52~~, in which:

(a) said power means and magnetic actuator means comprise a brushless DC motor having motor windings and laminations disposed radially about ~~said~~ an annular blood channel and having a motor rotor disposed therewithin, such that said annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) said rotary hydrodynamic pump impeller means comprise an axial or mixed flow pump impeller having a hub diameter ~~of the hub~~ smaller than the outside diameter of the motor rotor.

~~65~~. The device of claim ~~53~~, in which:

(a) said power means and magnetic actuator means comprise a brushless DC motor having motor windings and laminations disposed radially about said annular blood channel and having a motor rotor disposed therewithin, such that said annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) said rotary hydrodynamic pump impeller means comprise an axial or mixed flow pump impeller having a hub diameter ~~of the hub~~ smaller than the outside diameter of the motor rotor.

66. The device of claim 54, in which:

(a) said power means and magnetic actuator means

comprise a brushless DC motor having motor windings and laminations disposed radially about said annular blood channel and having a motor rotor disposed therewithin, such that said annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) said rotary hydrodynamic pump impeller means comprise an axial or mixed flow pump impeller having a diameter of the hub smaller than the outside diameter of the motor rotor.

67. The device of claim 52, in which:

(a) said power means and magnetic actuator means comprise a brushless DC motor having motor windings and laminations disposed radially about said annular blood channel and having a motor rotor disposed therewithin, such that ~~said~~ annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) the outside diameter of the motor rotor is equal to or greater than two thirds of the inside diameter of the motor windings and laminations but not so large as to excessively obstruct said annular channel through which the blood must pass.

68. The device of claim 53, in which:

(a) said power means and magnetic actuator means comprise a brushless DC motor having motor windings and laminations disposed radially about said annular blood channel and having a motor rotor disposed therewithin, such that said annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) the outside diameter of the motor rotor is equal to or greater than two thirds of the inside diameter ~~or~~ of the motor windings and laminations but not so large as to ~~excessibely~~ excessively obstruct said annular channel through which the blood must pass.

69. The device of claim 54, in which:

(a) said power means and magnetic actuator means

comprise a brushless DC motor having motor windings and laminations disposed radially about said annular blood channel and having a motor rotor disposed therewithin, such that said annular blood channel passes through the gap between the motor rotor and the motor windings generally referred to as the motor "air gap",

(b) the outside diameter of the motor rotor is equal to or greater than two thirds of the inside diameter or the motor windings and laminations but not so large as to excessibely obstruct said annular channel through which the blood must pass.

6 ~~70~~. The device of claim ~~52~~, including magnetic or mechanical thrust bearing means or a combination of both.

16 ~~71~~. The device of claim ~~53~~, including magnetic or mechanical thrust bearing means or a combination of both.

72. The device of claim 54, including magnetic or mechanical thrust bearing means or a combination of both.

7 ~~73~~. The device of claim ~~52~~, in which said power and magnetic actuator means include a magnetic coupling having permanent follower magnets mounted within the rotor and having rotary outer drive magnets mounted outside the bloodstream for rotation by a motive device such that rotation of the outer drive magnets causes rotation of the follower magnets and thus rotates the rotor.

17 ~~74~~. The device of claim ~~53~~, in which said power and magnetic actuator means include a magnetic coupling having permanent follower magnets mounted within the rotor and having rotary outer drive magnets mounted outside the bloodstream for rotation by a motive device such that rotation of the outer drive magnets causes rotation of the follower magnets and thus rotates the rotor.

75. The device of claim 54, in which said power and magnetic actuator means include a magnetic coupling having permanent follower magnets mounted within the rotor and having rotary outer drive magnets mounted outside the bloodstream for rotation by a motive device such that rotation of the outer drive

magnets causes rotation of the follower magnets and thus rotates the rotor.

8 ~~76~~. The device of claim 1 ~~52~~ in which said bearing means include:

(a) a smooth wear resistant small diameter shaft;

(b) a cylindrical sleeve composed of a wear resistant material, having an elongated hole through which said shaft passes of a diameter only slightly larger than the diameter of the shaft, such that only a minimal volume of blood occupies the gap between the shaft and the sleeve.

18 ~~77~~. The device of claim 11 ~~53~~ in which said bearing means include:

(a) a smooth wear resistant small diameter shaft;

(b) a cylindrical sleeve composed of a wear resistant material, having an elongated hole through which said shaft passes of a diameter only slightly larger than the diameter of the shaft, such that only a minimal volume of blood occupies the gap between the shaft and the sleeve.

78. The device of claim 54 in which said bearing means include:

(a) a smooth wear resistant small diameter shaft;

(b) a cylindrical sleeve composed of a wear resistant material, having an elongated hole through which said shaft passes of a diameter only slightly larger than the diameter of the shaft, such that only a minimal volume of blood occupies the gap between the shaft and the sleeve.

9 ~~79~~. The device of claim 1 ~~52~~ in which said bearing means include mechanical wear resistant thrust bearing means having a rotating and a stationary thrust bearing surface between which a small gap exists, said gap containing blood, and said thrust bearing elements so comprised and disposed that the periphery of

said gap is sufficiently well washed by the flow of blood thereacross that thrombus accumulation is prevented.

80. The device of claim 53 including mechanical wear resistant thrust bearing means having a rotating and a stationary thrust bearing surface between which a small gap exists, said gap containing blood, and said thrust bearing elements so comprised and disposed that the periphery of said gap is sufficiently well washed by the flow of blood thereacross that thrombus accumulation is prevented.

81. The device of claim 54 in which said bearing means include mechanical wear resistant thrust bearing means having a rotating and a stationary thrust bearing surface between which a small gap exists, said gap containing blood, and said thrust bearing elements so comprised and disposed that the periphery of said gap is sufficiently well washed by the flow of blood thereacross that thrombus accumulation is prevented.

82. The device of claim 52 in which the elements of said magnetic actuator means are so adapted as to provide axial forces to absorb all or part of the axial thrust load applied to said rotor as a result of rotation of the impeller within the blood and as a result of gravitational and inertial effects.

83. The device of claim 53 in which the elements of said magnetic actuator means are so adapted as to provide axial forces to absorb all or part of the axial thrust load applied to said rotor as a result of rotation of the impeller within the blood and as a result of gravitational and inertial effects.

84. The device of claim 54 in which the elements of said magnetic actuator means are so adapted as to provide axial forces to absorb all or part of the axial thrust load applied to said rotor as a result of rotation of the impeller within the

blood and as a result of gravitational and inertial effects.

~~85. A rotary hydrodynamic blood pump comprising:~~

a blood-pumping rotor including an impeller;

means to suspend the rotor for rotational motion within the bloodstream on a wire in tension that passes through a cylindrical hole in the rotor;

means to magnetically rotate the rotor within the bloodstream;

magnetic thrust-bearing means to maintain the rotor in proper axial position on the wire.

22 ~~86.~~ The blood pump of Claim ~~85~~ 21 in which the magnetic means provided to rotate the impeller include permanent magnets of a brushless DC motor mounted within the rotor and windings of the motor mounted outside the bloodstream surrounding the rotor.

23 ~~87.~~ The blood pump as described in Claim ~~85~~ 21 in which the magnetic means to rotate the impeller include a magnetic coupling having permanent follower magnets mounted within the rotor and having rotary drive magnets mounted outside the bloodstream for rotation by a motive device such that rotation of the outer drive magnets causes rotation of the follower magnets and thus rotates the impeller.

24 ~~88.~~ The blood pump of Claim ~~86~~ 22 in which the impeller is suspended on the rotor by pins or utilizes blades such that a major portion of the bloodstream passing through the device washes across each end of the rotor to retain high flow in the vicinity where the bearing wire emerges from the rotor and thereby also prevents thrombus formation.

25 ~~89~~. The blood pump of Claim 23 ~~87~~ in which the impeller is suspended on the rotor by pins or utilizes blades such that a major portion of the bloodstream passing through the device washes across each end of the rotor to retain high flow in the vicinity where the bearing wire emerges from the rotor and thereby also prevents thrombus formation.

a.

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~~90. An intraventricular artificial heart comprising:~~

a hydrodynamic blood pump as defined in Claim 88 of sufficiently small size and anatomic configuration to be implanted within the chamber of the left ventricle of the heart and produce adequate flow and pressure to provide the entire output for the systemic circulation;

inflow and outflow connector means to permit surgical implantation within the heart;

control means to vary the cardiac output according to the physiological demand of the body and optionally to provide a pulsatile flow by repeatedly speeding up and slowing down the speed of rotation of the impeller.

91. An intraventricular artificial heart comprising:

a hydrodynamic blood pump as described in Claim 87 of sufficiently small size and anatomic configuration to be implanted within the chamber of the left ventricle of the heart and produce adequate flow and pressure to provide the entire output for the systemic circulation;

inflow and outflow connector means to permit surgical implantation within the heart;

control means to vary the cardiac output according to

the physiological demand of the body and optionally to provide a pulsatile flow by repeatedly speeding up and slowing down the speed of rotation of the impeller.